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SUMMARY REPORT OF NATIONAL BUREAU OF STANDARDS RESEARCH ON PRESERVATION OF RECORDS

By
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SUMMARY REPORT OF NATIONAL BUREAU OF STANDARDS RESEARCH ON PRESERVATION OF RECORDS

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ABSTRACT

The results of systematic studies of the problem of preserving valuable records are summarized so as to have the more important information available in one publication. Most of it has been previously reported in more complete detail in several previous publications.

A survey of material stored in libraries and of the surrounding conditions, showed that many valuable publications were badly deteriorated. Light, adverse temperature and humidity, acidic pollution of the air, and impurities in paper were indicated as the main deteriorative agents. Through exposures of papers to sulphur dioxide gas, with measurement of the weakening effect, and the testing of papers from old books that had been stored in various localities, this product of combustion was proved a potential destroyer of all classes of papers. Experimental tests in a library demonstrated that this acidic gas can be completely removed by washing the air with alkaline water. The destructive effect of light is emphasized by data showing its rapid weakening effect on all grades of papers. In the discussion of the ventilation of libraries, the removal of dust, and the maintenance of a medium degree of temperature and humidity are recommended. Carefully controlled air conditioning is desirable. Extensive tests of old newspapers and books showed the deteriorative effect of crude fibers, such as ground wood; papers containing them were generally in bad condition as contrasted with the generally good condition of papers composed of chemically purified fibers. A classification of book papers for record use is suggested. Relative to protection against insects, the results of a study of fumigants showed that several effective types could be used without damaging paper. Studies of protective coatings for papers indicated that both japanese tissue and transparent cellulose acetate sheeting are suitable. The common type of writing ink was found to be deteriorative to paper, but an ink prepared according to a different formula had a negligible effect. For preservation by reproduction, photostat prints on permanent paper were found suitable, and tests of cellulose acetate film indicated that it offered considerable promise for the purpose.

These investigations were made with the assistance of a fund granted to the National Research Council by the Carnegie Foundation. The study of films was partially supported by the National Archives.

This is a revision of the summary report contained in Miscellaneous Publication M144, and includes new material dealing with paper quality, insects, protective coatings, and preservation by reproduction.

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I. INTRODUCTION

The librarian is the custodian of the records of the past upon which the progress of the future must be founded. His responsibility is great. If some future generation finds that important records have changed to dust, the loss to civilization may be irreparable. The proper discharge of this duty requires that he assume responsibility for the physical quality of the documents which he takes into custody, and that he store them under such conditions as to promote maximum longevity. It is the plain duty of the public to see that librarians are given adequate support and permitted sufficient freedom of action to accomplish their task.

Cheap paper has been a potent factor in the development of civilization. It has made both learning and news cheaply and universally available, and has therefore become an absolute necessity in our present scheme of existence. But the present generation has learned that cheap paper is not a quality product. The demand for low price has led to the introduction of new raw materials; the demand for enormous quantities has prevented the use of great care in manufacturing. There is a tremendous and vitally important market for such paper, but we now know that this market does not include the printing of records designed for the use of future generations.

The continued concentration of our population in cities has produced a new problem for librarians to face. The urban atmosphere, polluted by smoke from heating and power plants and exhaust gases from automobiles, less exposed to the purifying action of sunlight, overheated by multiple reflections from paved streets and brick walks, is far different from the fresh, pure air of the open country, which was our customary living environment a hundred years ago.

The preceding generation did not consider these things. Many important records were printed on impermanent paper and/or were stored under such conditions that they are now no longer serviceable. The League of Nations, through its international cooperation, found the present situation serious. The American Library Association decided to do something about it. Largely on the initiative of H. M. Lydenberg, of the New York Public Library, the Carnegie Foundation was persuaded to finance the project. Funds were deposited with the National Research Council to support fellowships at the National Bureau of Standards. These funds were supplemented by others appropriated by the United States Congress.

Work started on August 26, 1929, under the auspices of the following advisory committee, which was appointed by the National Research Council, and of which the chairman of the Division of Chemistry and Chemical Technology of the Council was ex-officio chairman:

Helen U. Kiely, chief chemist, American Writing Paper Co., Inc., Holyoke, Mass.
H. M. Lydenberg, assistant director, New York Public Library, New York, N. Y.
H. G. Knight, chief, Bureau of Chemistry and Soils, Washington, D. C.
W. D. Harper, president, W. D. Harper, Inc. (paper merchants), 225 Fourth Avenue, New York, N. Y.
G. A. Richter, director of Paper Research, Brown Co. (pulp and paper manufacturers), Berlin, N. H.
B. L. Wehmhoff, technical director, Government Printing Office, Washington, D. C.

R. E. Flynn, Union Guardian Trust Co., Detroit, Mich., chairman, Paper Standardization Committee of National Association of Purchasing Agents.

A. M. Chase, Dodd, Mead & Co., New York, N. Y., representing National Association of Book Publishers, 448–449 Fourth Avenue, New York, N. Y.

M. Krimmel, assistant director of laboratories, Hammermill Paper Co., Erie, Pa.

Hervey J. Skinner, president, Skinner and Sherman, 246 Stuart Street, Boston, Mass.

The studies dealing with the preservation of records contained on paper, with the exception of the work on fumigants, were discontinued July 26, 1933, because of exhaustion of the available funds. The study to find whether certain fumigants have any deleterious effect on paper was undertaken later at the request of The National Archives, and with the assistance of personnel supplied by that institution.

The results of this work, as set forth on the following pages, comprise a description of conditions as they existed in libraries when the work was initiated. This is based on a survey of conditions in libraries and on an examination of records therein. Attention is called to the obvious wisdom of selecting a quality paper for permanent records.

Storage conditions are, or should be, under the control of the librarian; and he is advised in this report concerning those factors which may cause trouble, and what conditions should be maintained for the maximum longevity of the records in his keeping.

This work is not completed. Considering the harmful effect of light, more information should be obtained to assist in choosing the least injurious form of illumination in libraries. The physical and chemical reactions which occur when paper deteriorates should be ascertained, for such fundamental knowledge might lead to new ways of stabilizing paper.

Because of the increasing importance of photographic films of the motion-picture type for documentary and educational uses, the Bureau was requested to extend its study of the preservation of records to this form of material. This was made possible by an additional fund deposited with the National Research Council by the Carnegie Foundation, and a fund allotted by the Division of Motion Pictures and Sound Recordings of The National Archives. This work was initiated in June 1935. The National Research Council is interested in the cellulose acetate film because it is no more inflammable than paper, and because of its apparent stability—properties lacking in the cellulose nitrate film used for the theater motion pictures. The National Archives are interested in both acetate and nitrate films because they will store and use both. The following advisory committee for this work was appointed by the National Research Council:

H. M. Lydenberg (chairman), director, New York Public Library, New York, N. Y.

Robert C. Binkley, chairman of Joint Committee on Materials for Research of the American Council of Learned Societies and the Social Science Research Council, Western Reserve University, Cleveland, Ohio.

John G. Bradley, chief, Division of Motion Pictures and Sound Recordings, The National Archives of the United States, Washington, D. C.

E. K. Carver, Eastman Kodak Co., Rochester, N. Y.

Herford T. Cowling, The National Archives of the United States, Washington, D. C., representing the Society of Motion Picture Engineers.

V. B. Sease, Du Pont Film Manufacturing Co., Parlin, N. J.

The Chairman of Division of Chemistry and Chemical Technology, National Research Council, Washington, D. C.

The information so far obtained indicates that cellulose acetate film is a very stable material if used and stored with the precautions stated herein.

The first summary of this information was issued as Miscellaneous Publication M144, and this revised report was prepared to add new material relating to paper quality, insects, protective coatings, and preservation by reproduction. Most of the various studies have been reported in more detail in separate papers which are referred to in the text. Except as noted in the text, they were conducted in the Bureau Paper Section.

II. PLAN OF RESEARCH

Definite data as to the optimum conditions of storage for paper were found to be meager. In fact, perusal of the literature showed that prior to the work herein reported, no systematic, organized research to determine the causes of the deterioration of paper in libraries and similar depositories, and to find means of minimizing or eliminating this deterioration, had ever been reported. This dearth of reliable information was most unfortunate, because proper manipulation of storage conditions is the only means available to the librarian for prolonging the useful life of books and manuscripts. The literature did, however, record that certain agencies, namely, light,[1 2 3 4 5] acid gases,[6 7] varying temperatures, and relative humidity,[8 9] and various pests[10 11 12 13 14] such as insects, mice, molds, and other fungi have been considered harmful to paper in the past, although definite data were lacking. It was, therefore, necessary to formulate a plan of research designed to define clearly the agents of deterioration caused by storage and to find means of minimizing or eliminating the action of these agents on stored records.

After an extensive review of the literature to avoid duplication of work, a research program was formulated giving consideration to all factors indicated in the literature as having an important bearing on the whole problem of preserving records. This comprised: first, surveys of important public libraries to correlate storage conditions with deteriorative effects, with consideration of locality, illumination, climate, inside atmospheric conditions, conditions of use, and condition of stored material as determined by inspection and tests; second, laboratory and library investigations to develop inhibitive measures for any deteriorative effects of storage conditions found; third, studies of effect of components of record material, such as paper and ink; and fourth, protective and reproductive measures for perpetuating records, such as use of protective coatings and photographic reproduction on stable material.

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[1] P. Klemm, Papier Ztg. **27**, 961–963 (1902).
[2] C. Schwalbe, Wochbl. Papierfabr. **38**, 1472 (1907).
[3] Viktor Schoeller, Wochbl.. Papierfabr. **43**, 3222 (1912).
[4] B. Haas, Papierfabr. **12**, 891, 919 (1914).
[5] A. B. Hitchens, Paper **22**, 11 (1928).
[6] A. Girard, Am. chim. phys. **24**, 337 (1881).
[7] Aribert and Bouvier, La Papeterie, **42**, 338, 386 (1920).
[8] J. Norris, Library J. **38**, 16 (1913).
[9] O. Braums, Pulp and Paper Mag. Can. **26**, 11, 165 (1928).
[10] C. Houlbert, Les Insectes ennemis des Libres, Paris (1907).
[11] Arturo Scarone, El libro y sus enimigos, Montevideo (1917).
[12] W. R. Reinich, Am. J. Phar. **83**, 503 (1911).
[13] Pierre, Compt. rend. **164**, 230 (1917).
[14] V. Galippe, Compt. rend. **169**, 814 (1919).

III. SURVEY OF STORAGE CONDITIONS IN LIBRARIES

A survey of libraries was undertaken to ascertain the kind and amount of equipment which librarians have available for the protection of the records in their charge, and to get information about the visible effects of light, dust, dampness, and similar factors.

Thirteen libraries were selected to give a fair representation of conditions throughout the United States in both urban and rural localities. Eight of these were personally inspected; information from the other five was obtained by correspondence.

Details of equipment are shown in table 1.

Table 1 shows that of the 13 libraries listed only 4 possessed the equipment necessary for the removal of dust from the incoming air of their ventilating systems. Oil filters were used in three of the four libraries attempting dust removal. The elimination of dust from library air is very important because dust particles, in addition to their abrasive action upon the paper and bindings of stored material, act as nuclei for the condensation of acidic moisture.[15] Every library inspected attempted to reduce the amount of dust in the stacks and on the books by systematic dusting. In several instances small hand vacuum cleaners were extensively used.

Six of the libraries possessed machinery for humidity control, but in two cases the apparatus was not in use at all, and in a third instance the plant was effective only in cool weather because of the lack of a refrigerator. An attempt was made, several years previously, to use the third-mentioned plant in the summer, but when the advent of a spell of cooler weather precipitated the moisture from the air in the stacks upon the books stored therein, resulting in extensive damage from molding, the attempt was abandoned. All of the equipment in full-time use was of the water-curtain type, with no means of regulating the temperature of the water, save in one instance where modern thermostatic control had just been installed. The average library using average equipment could not control the humidity of the air within its stacks very closely.

The situation regarding the protection of books from the action of daylight was considerably better than that with respect to the other phases of protection, for 10 of the 13 selected libraries minimized the effect of the actinic rays of light by the total elimination of windows in 3 cases, or by the use of thick glass in the remaining 7 examples. In only one instance was sunlight admitted freely to the stacks and it may be noted that excessive deterioration was apparent in this case. Book stacks, in general, were found to be lighted by small, frosted incandescent bulbs, which were switched on and off as required. This is a very desirable practice.

"Yellowing" and "brittling" were observed in hot, dry, and dusty places in the path of direct sunlight. Books stored in diffused light were in a superior condition.

Dusty papers were frequently observed to be discolored and quite often brittle, but no general rule for the correlation of these facts could be formulated.

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[15] Monnett, Osborn, Smoke Abatement, U. S. Bur. Mines Bul. 273 (1927).

TABLE 1.—*Survey of conditions of storage in libraries*

Library	Method of dust removal	Method of heating	Method of ventilation	Method of humidification of air	Kind of light in stacks	Method of combating effects of actinic rays of light	Method of combating effects of acidic pollution of air.
A [1]	Oil filter	Steam radiators	Direct fan system	Water spray	Sunlight and artificial	None	Oil filter and water spray.
B [1]	Water curtain	do	do	Water curtain [2]	Very dull artificial	Dark stacks	Water curtain.
C [1]	None	Hot air and steam radiators.	do	None	Diffused daylight and dull artificial.	Thick glass	None.
D [1]	Not in use	Steam radiators	do	Not in use	Very dull artificial	Dark stacks	Do.
E [1]	do	do	do	do	Diffused daylight and dull artificial.	Thick glass	Do.
F [3]	None	Indirect steam	Fans; plenum chamber [4]	None	Dull artificial	do	No information.
G [3]	do	No information	Plenum chamber exhaust	do	No information	Art glass	None.
H [3]	do	do	Windows	do	do	None	Do.
I [1]	Oil filter	Steam radiators	Direct fan system	Water curtain	Very little diffused daylight and dull artificial.	Thick glass	Oil filter and water curtain.
J [3]	None; vacuum cleaner on shelves.	do	No information	None	No information	Glass (ground and frosted).	None.
K [2]	None	Indirect steam	Fans; steam chamber	Steam chamber	Dull artificial	Dark stacks	Do.
L [3]	do	Windows	None	No information	No information	No information	Do.
M [1]	Oil filter	Hot air	Direct fan system	Automatic humidifier.	Dull artificial	Dark stacks	Oil filter.

[1] Information obtained by inspection.
[2] Temperature of water thermostatically regulated.
[3] Information obtained by correspondence.
[4] A chamber for heating the air before admission to stacks.

No damp places were observed at the time of this survey but several spots were pointed out as being damp at other seasons. In these places, the papers examined seemed soft and "fuzzy", bearing a white powder which could readily be brushed off. They also showed brown splotches known as "foxing."

Apparently little difficulty was being experienced with pests, as is to be expected with the precautions taken to insure cleanliness and good ventilation.

For further details on this subject, reference may be made to the preliminary report. (See reference 26.)

IV. EFFECT OF AIR POLLUTED WITH SULPHUR DIOXIDE

The earliest known published record of deterioration by sulphur dioxide is to be found in a lecture given in April 1843 by Michael Faraday, who declared that the rapid decay of leather bindings and leather upholstery in the Athenaeum Club of London was caused by the effects of heat and sulphur fumes emanating from the illuminating gas used. He recommended more thorough ventilation by a system of ducts leading the products of combustion from each burner to a central chimney.

No information as to the effect of illuminating gas fumes upon paper was available until 1898, when the Committee of the Royal Society of Arts on the Deterioration of Paper reported as follows: "Actual disintegration has been found to occur in all grades of paper; it is the result of chemical change of the fibers themselves, and in some cases could be traced to the effect of illuminating gas upon the atmosphere of the rooms in which the books had been stored."[16] The deleterious effects of gas fumes upon paper were further emphasized by Veitch[17] and by Aribert and Bouvier,[18] who recommended the elimination of illuminating gas from libraries.

With the almost universal use of electricity for artificial illumination, danger to books from gas fumes was thought to be ended, although the appearance of articles describing the effects of smoke on vegetation[19] and building materials[20] in industrial localities, as well as the deleterious action of the sulphur dioxide present in the fumes emanating from certain types of smelters,[21 22] indicated that atmospheric pollution was prevalent to a greater degree than had been hitherto realized. In recent years many investigations to determine the extent of this nuisance as well as means of abating it[23 24 25] have been conducted. A study of statistics from 15 American and European cities[26] showed the sulphur dioxide content of city air to vary from 0.2 to 3 parts per 1,000,000 parts of air, and an annual precipitation of sulphuric acid averaging from 11 to 190 tons per

[16] J. Royal Soc. Arts **46**, 597–601 (1898).
[17] F. P. Veitch, U. S. Dept. Agr. Yearbook, 261 (1908).
[18] Aribert and Bouvier, *The diseases of paper*, La Papeterie **42**, 338, 386 (1920).
[19] J. F. Clevinger, The Effect of Smoke on Vegetation, Mellon Institute Smoke Investigation, Bul. 7 (1913).
[20] The Effect of Smoke on Building Materials, Mellon Institute Smoke Investigation, Bul. 6 (1913).
[21] J. A. Holmes, E. C. Franklin, and R. A. Gould, Report of the Selby Smelter Commission, U. S. Bur. Mines Bul. 98 (1915).
[22] J. K. Haywood, J. Am. Chem. Soc. **29**, 998 (1907).
[23] Recent Progress in Smoke Abatement in Manchester, Mellon Institute Smoke Investigation, Bul. 10 (1922).
[24] H. B. Meller, Mech. Eng. **48**, 11a, 1275 (1926).
[25] B. A. Burrell, Proc. Leeds Phil. and Lit. Soc., Sci., Sec., **1**, pt. 3, 116 (1926).
[26] A. E. Kimberly and J. F. G. Hicks, Jr., A Survey of Storage Conditions in Libraries Relative to the Preservation of Records, Misc. Pub. BS 128 (1931).

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square mile. Additional evidence of the increasing pollution of modern urban atmospheres is given by an investigation by the National Bureau of Standards of the causes of "winter damage" or the rotting of damp cotton fabric upon exposure to outside air experienced by laundries throughout New England.[27] Atmospheric sulphur dioxide, which is oxidized on the fabric to sulphuric acid, was found to be the cause of this rotting. This action was accelerated by the presence of minute quantities of iron or of chlorine bleaching residues in the fabric.

Despite the great amount of evidence at hand to show the increasingly acidic nature of modern atmospheres, no information of the effect on paper of concentrations of sulphur dioxide such as are commonly encountered in the air of cities was found in the literature. However, consultation with librarians in different localities indicated a belief that the paper of books stored in city institutions deteriorated more rapidly than the paper of similar volumes kept in country or suburban localities, even though the wear and tear incident to use was approximately the same for each depository. In the light of even the meager data on air pollution already considered,[28] the possibility that the greater deterioration of books stored in cities might be caused by the action of sulphur dioxide was too obvious to be passed over. It was therefore decided to formulate a research program having as its objectives:

1. The determination of the effect of low concentrations of sulphur dioxide, such as are commonly found in the air of large cities, upon paper.
2. The comparison of the effect on similar books of storage in polluted and unpolluted areas with particular reference to the action of sulphur dioxide.
3. If sulphur dioxide is important as a deteriorant of paper, to find means of eliminating it from the air of libraries.

The first phase of this program was initiated by exposing a series of commercial book and writing papers of various fiber compositions to the action of a sulphur dioxide-air mixture, in which the sulphur dioxide content was maintained at 2 to 9 parts per 1,000,000 parts of air. The exposure was carried out at 30° C (86° F) and 65 percent relative humidity for 240 hours.

Twenty sheets (8 by 10½ inches) of each paper to be exposed were conditioned at 21° C (70° F), and 65-percent relative humidity for 48 hours, after which they were removed to the test cabinet where they were suspended and exposed for the required time. The cabinet, illustrated in figures 1 and 2, was a double-walled box, fashioned of sheet metal and glass, the inside dimensions of which were 18 by 30 by 20 inches. It was equipped with suitable apparatus for the control of temperature, humidity, and sulphur dioxide content, a detailed description of which may be found in an earlier publication.[29]

After 10 days exposure the paper samples were washed with nitrogen for 24 hours and then tested for folding endurance, acidity, copper number, and alpha-cellulose content. The procedures used for the determination of alpha-cellulose content and copper number were developed by the National Bureau of Standards specifically for

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[27] John B. Wilkie, *Laundry "winter damage"*, BS J. Research 6, 593 (1931) RP294.
[28] See footnote 26.
[29] Arthur E. Kimberly, *Deteriorative effect of sulphur dioxide upon paper in an atmosphere of constant humidity and temperature*, BS J. Research 8, 159 (1932) RP407.

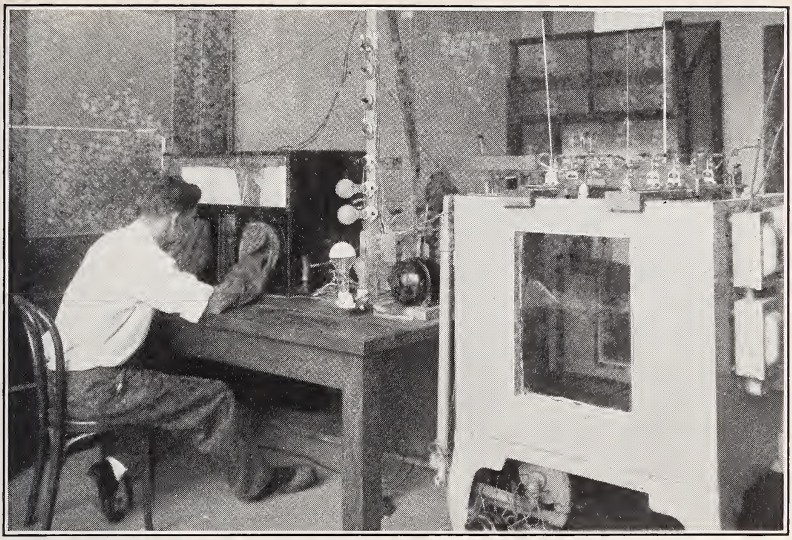

FIGURE 1.—*Front view of apparatus for exposure of paper to polluted air, showing means of manipulating samples.*

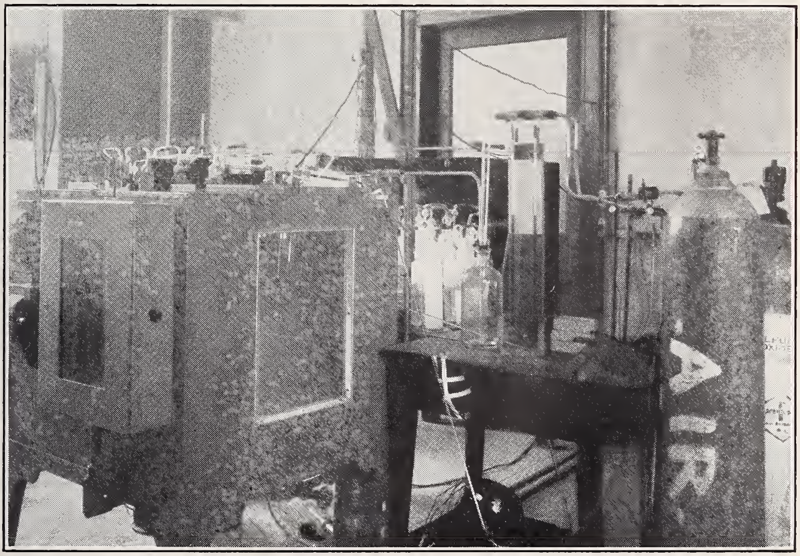

FIGURE 2.—*Rear view of apparatus for exposure of paper to sulphur dioxide, showing control accessories.*

testing paper.[30] The alpha-cellulose content of paper is that part of the cellulose material which is insoluble in a sodium hydroxide solution of mercerizing strength (17.5 percent of NaOH) under certain specified conditions, and is regarded as a measure of the amount of unmodified cellulose which the material contains. A high alpha-cellulose content is considered an indication of superior condition in paper. The copper number, on the other hand, is a measure of the amount of modified or deteriorated cellulose present and, when high, is regarded as an indication of poor condition in paper. The acidity of the papers was determined by the fiber-suspension method.[31]

The results of these tests show that in every case a decrease in folding endurance and an increase in acidity occurred, and that these changes were usually of considerable magnitude. The increase in acidity, while significant in any event, is more so if caused by sulphuric acid formed by the oxidation of sulphur dioxide upon the paper. There are good grounds for such an assumption since Wilkie [32] showed that such oxidation takes place upon cotton fabric, especially in the presence of iron,[33] [34] [35] and since both cotton fabric and paper are essentially cellulose. The analogy is completed by the fact that most papers contain small amounts of iron derived from iron equipment, water, and reagents used in the paper-making processes. Sulphuric acid, being nonvolatile at ordinary temperatures, would remain upon the paper and exert a continuous effect. Either sulphurous or sulphuric acid is capable of promoting acid hydrolysis [36] which results in the embrittlement of paper fibers and their eventual crumbling.

Further consideration of the data shows that exposure to sulphur dioxide caused a distinct increase in copper number accompanied by relatively small changes of the alpha-cellulose content (that is, 8 out of 14 specimens show changes of 0.5 percent or less). This would indicate that the first point of attack is that portion of the material of the sheet which had originally been partially modified by "hydration" in the beaters or otherwise. The embrittlement shown by decreased folding endurance is added evidence for this point of view, as folding endurance is commonly considered to be partially dependent on the cementing action of the gel-like portion of the paper fiber. It is not known whether or not a longer exposure to the action of sulphur dioxide would result in more pronounced changes in alpha-cellulose content.

On comparing the embrittlement of the papers with their qualities for permanent record use as shown in other publications, [37] [38] it was found that some of the best papers were the least resistant to sulphur dioxide. This is illustrated for the book papers by a medium quality paper having an alpha-cellulose content of 83 percent and a copper number of 3.07 which failed completely under the heat test,[39] but showed practically no change upon exposure to sulphur diox-

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[30] J. O. Burton and R. H. Rasch, *Determination of the alpha-cellulose content and copper number of paper*. BS J. Research 6, 603 (1931) RP295.
[31] See footnote 29.
[32] See footnote 27.
[33] S. F. Cooke, *Role of certain metallic ions as oxidation catalysts*, J. Biol. Chem. 10, 289 (1926).
[34] L. P. Wilson. *Catalytic action in the oxidation of cellulose*. J. Soc. Chem. Ind. 39, 177T (1920).
[35] O. Baudisch, and D. Davidson, *Catalytic oxidation by means of complex iron salts*, J. Biol. Chem. 11, 50 (1927).
[36] Heuser, West and Esselen, Textbook of Cellulose Chemistry, 121 (McGraw-Hill Book Co., 1926).
[37] J. O. Burton, *Permanence studies of current book papers*, BS J. Research 7, 429 (1931) RP349.
[38] R. H. Rasch, *A study of purified wood fibers as a paper-making material*, BS J. Research 3, 469 (1929) RP107.
[39] R. H. Rasch, *Accelerated aging test for paper*, BS J. Research 7, 465 (1931) RP352.

ide, and a paper suitable for permanent record use, having an alpha-cellulose content of 95 percent and a copper number of 0.40, which withstood the heat test with very little change, but lost about 30 percent of its folding endurance upon treatment with sulphur dioxide. The writing papers examined show a similar tendency. For instance, one sample having an alpha-cellulose content of 78.9 percent and a copper number of 3.25, and another with an alpha-cellulose content of 78.5 percent and a copper number of 3.67, both low grade papers, showed poor stability under the heat test, but were relatively unaffected by sulphur dioxide. The opposite was true of two permanent record papers having alpha-cellulose contents of 85.3 and 91 percent and copper numbers of 1.71 and 1.06, respectively.

These findings show that even the best grades of the papers examined were not proof against the deteriorating action of air polluted by sulphur dioxide, which is in accord with the findings of Richter.[40]

Table 2.—*Effect of temperature and relative humidity on action of sulphur dioxide on paper* [1]

Paper no.	Fiber composition			Temperature	Relative humidity	Decrease in folding endurance [2]	Increase in acidity
	Rag	Sulphite	Soda				
	Percent	*Percent*	*Percent*	°C	*Percent*	*Percent*	*Percent*
94001 book paper	----------	40	60	30	65	14	38
				40	40	17	64
				40	65	29	126
				40	80	48	189
94008 bond paper	60	40	----------	30	65	7	101
				40	40	6	62
				40	65	11	198
				40	80	31	352
94011 bond paper	100	----------	----------	30	65	14	99
				40	40	22	155
				40	65	26	194
				40	80	90	391

[1] 240 hours exposure to 2 to 9 parts sulphur dioxide per 1,000,000 parts of air.
[2] Average of machine and cross directions.

In order to determine the effect of temperature and relative humidity upon the deterioration of paper due to sulphur dioxide, several selected specimens were exposed to the action of 2 to 9 parts sulphur dioxide per 1,000,000 at 40° C and 40-, 65-, and 80-percent relative humidity, respectively, for 240 hours. Table 2 shows the effect of such exposure upon three papers. It will be noted that the degree of deterioration increases markedly as the temperature and relative humidity are raised. These data are shown as they have not been published elsewhere.

However, regardless of the mechanism of the reaction, the mere fact that sulphur dioxide in concentrations approaching those actually encountered in the air of cities may cause paper to deteriorate markedly in so short a time as 10 days is an indication of the gravity of the problem of paper preservation.

In view of the results of the work just described, it would not be surprising if a book which had been exposed to an urban atmosphere, polluted by sulphur dioxide, deteriorated to a greater extent than a similar book stored in a country or suburban locality relatively free from air pollution. Accordingly, a group of 34 deteriorated books

[40] G. A. Richter, Ind. Eng. Chem. 23, no. 4, 371 (1931).

was obtained through the courtesy of the New York Public Library, and a list of these titles was sent to libraries throughout the United States with the request that duplicates be forwarded for examination. The libraries were further requested to submit for examination any outstanding examples of paper deterioration or preservation which could be spared. By this means, 229 books published during the period 1720 to 1930, as well as 85 duplicates of 31 different titles, were collected from 23 libraries in widely separated localities.

The similar books were carefully inspected to insure uniformity of edition and date of printing, and the records of the contributing institutions were checked so as to include for examination only those books which had been subjected to approximately the same degree of use while in circulation. This final process of selection yielded a group of 11 titles, each represented by 2 or more volumes. The paper of these books was tested for alpha-cellulose content, copper number, acidity, and folding endurance, using the procedures previously discussed.[41] The same portion of each different book was tested to insure absolute similarity of sample.

A careful survey of the surroundings of each contributing institution was made in person, or by correspondence when a personal investigation was impracticable, in order to determine whether the atmosphere in the vicinity of the library was polluted or relatively free from acid gases. For example, the New York Public Library is situated in the heart of New York City and surrounded by high buildings, a condition under which one might expect to encounter a marked degree of atmospheric pollution. Analyses of air in this locality show 0.8 to 1.2 parts of sulphur dioxide per 1,000,000 parts of air.[42] Similarly, the University of Pennsylvania Library is located in downtown Philadelphia, bounded on one side by main-line railroad tracks and in close proximity to an oil refinery and numerous chemical plants. The sulphur dioxide content of air in this vicinity was found to vary from 0.1 to 1.8 parts of sulphur dioxide per 1,000,000 [43] parts of air, and damage to the foliage of elm trees in the University Botanical Gardens has been observed by members of the university staff. With these highly polluted localities may be contrasted that of Iowa State College situated several miles from the center of Ames, Iowa, in an area relatively free from industrial pollution.

It was found that the paper of books stored in libraries where the atmosphere is characteristically urban (for example, New York Public Library) contained more acid than other copies of the same books kept in libraries where the atmosphere is less likely to be polluted (for example, Iowa State College). This increased acidity was invariably accompanied by decreased strength and in most cases by an increased copper number and a decreased alpha-cellulose content, all of which are indications of poor condition in paper.

The principal difference between storage conditions in cities and storage conditions elsewhere is the presence in urban air of measurable quantities of sulphur dioxide. This gas, a product of the combustion of fuel and of certain industrial processes, has already been shown to be harmful to paper, and papers exposed to its action exhibit an

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[41] Arthur E. Kimberly, *Deteriorative effect of sulphur dioxide upon paper in an atmosphere of constant humidity and temperature*, BS J. Research 8, 159 (1932) RP407; J. O. Burton and R. H. Rasch, *Determination of the alpha-cellulose content and copper number of paper*, BS J. Research 6, 603 (1931) RP295.

[42] Communication from the Bell Telephone Laboratories.

[43] Information from the University of Pennsylvania Botany Department.

abnormally high acidity. Comparison of the acid content of paper after natural aging for 4 years in an atmosphere relatively free from sulphur dioxide, and after exposure for 240 hours to the action of 2 to 9 parts of sulphur dioxide per 1,000,000, showed that the acidity of the specimen exposed to the action of sulphur dioxide was markedly higher than that of the naturally aged specimen of the same paper. Since it has already been shown that the acidity of books stored in large cities, such as New York and Philadelphia, was usually considerably higher than that of similar books stored in country or suburban libraries, and that sulphur dioxide, which in the process of acting on paper produces high acidity in the paper, is present in the air of such cities, it seems reasonable to ascribe the greater deterioration noted in the books from city institutions largely to the action of sulphur dioxide. (See reference 50, p. 21.)

Since it has been definitely established that sulphur dioxide is one of the principal factors governing the deterioration of paper, the necessity of providing protection for valuable books and records against the action of this gas is very evident. The elimination of sulphur dioxide by washing the library air was thought to be the most feasible method, as regulation of the temperature and relative humidity of air in the storage spaces by means of air-conditioning systems is already accepted as the best practice. However, the efficiency of an air-conditioning system of the conventional type with respect to the removal of acid gases was not known. It, therefore, seemed desirable to learn whether washing air in the customary manner completely removes sulphur dioxide and, if not, how the air-conditioning procedure can be modified to provide air for libraries that is completely free from that harmful constituent.

The conduct of the work as planned required the use of a library equipped with suitable air-conditioning machinery. The cooperation of the Folger Shakespeare Library, Washington, D. C., in this respect was therefore secured, as its facilities include an air-conditioning system designed to provide the proper atmospheric temperature and humidity within the stacks and vaults. The Carrier Engineering Corporation, makers of the air-conditioning machinery on which the tests were made, assisted through the services of an engineer, as did the Metropolitan Refining Co., specialists in water treatment.

The sulphur-dioxide content of the air before and after washing was determined by a slight modification of the method of Griffin and Skinner.[44] A further discussion of the air-conditioning machinery and of the method of analysis will be found in another report.[45]

The hydrogen-ion concentration of the wash water in the air-conditioning system was frequently determined colorimetrically in order to find the relationship between the amount of sulphur dioxide in washed air and the hydrogen-ion concentration of the wash water.

It had been previously suggested that the efficiency of existing air-conditioning systems with respect to removal of sulphur dioxide might be increased by raising the alkalinity of the wash water.[46] This was accomplished in the course of these experiments by adding a mixture of certain alkaline salts at a rate sufficient to maintain the

[44] S. W. Griffin and W. W. Skinner, *Small amounts of sulphur dioxide in the atmosphere,* Ind. Eng. Chem. 24, 862 (1932).
[45] A. E. Kimberly and A. L. Emley, A Study of the Removal of Sulphur Dioxide from Library Air, Misc. Pub. BS 142 (1933).
[46] A. E. Kimberly and J. F. G. Hicks, Jr., A Survey of Storage Conditions in Libraries Relative to the Preservation of Records, Misc. Pub. BS 128 (1931).

hydrogen-ion concentration of the wash water within the range pH 8.0 to 9.0. This particular mixture of chemicals forms a passive gelatinous deposit upon metal surfaces, thereby retarding corrosion due to contact with water. In localities where a high degree of atmospheric pollution is encountered, the metal parts of air-conditioning systems corrode so rapidly, if preventive measures are not taken, that complete replacement has in certain cases become necessary after less than a year of operation. The hydrogen-ion concentration of the wash water in one system, where rapid deterioration was noted, dropped from pH 7.4 to pH 6.0 in the course of 8 hours of operation, because of the absorption of acid from the air washed. It is obvious that protection against corrosion is necessary under such conditions.

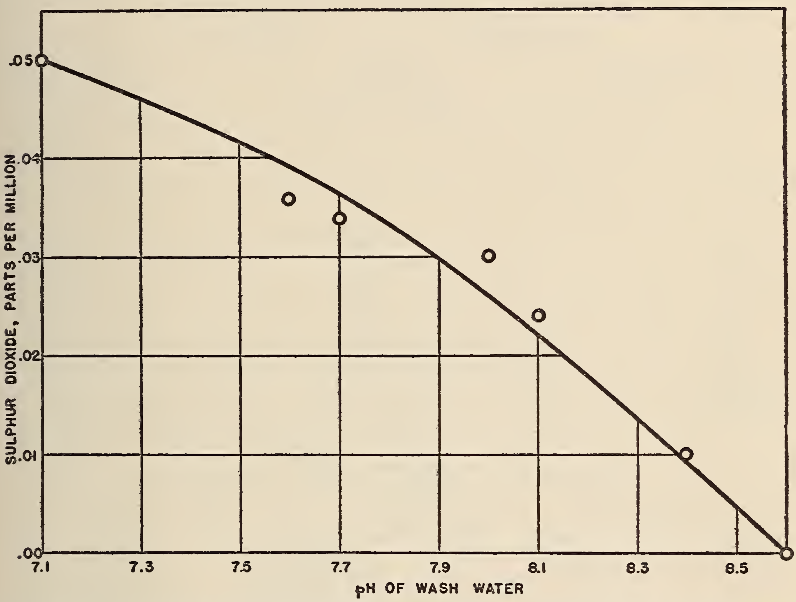

FIGURE 3.—*Comparison of the effect of washing with untreated and treated water on the sulphur-dioxide content of library air.*

Figure 3 gives the average results of the experimental work for each day from January 6 to February 16, 1933. It compares the sulphur dioxide of the untreated air entering the library with that of the washed air inside, with reference to the effect of washing with untreated water and water treated with the alkaline mixture. Figure 3 also shows the three successive changes or different treatments of the wash water, with the varying hydrogen-ion concentrations which characterized them. From January 6 to 24 the wash water was untreated and unchanged, though enough fresh water was continuously added to make up for that lost by evaporation. During this period the hydrogen-ion concentration of the wash water averaged pH 7. From January 25 to February 4 the water was treated with the alkaline mixture already described at such a rate that the hydrogen-ion concentration of the resulting solution fell only momentarily below pH 8.6. On February 6 the system was drained completely and refilled with fresh, untreated water of pH 7.7.

It is evident from figure 3 that air washed with untreated water in an air-conditioning system of the customary type, though containing less sulphur dioxide than unwashed air, was still appreciably contaminated. Figure 3 shows further that complete removal of sulphur dioxide was effected by washing the air with treated water. Although the sulphur dioxide content of the unwashed air varied from hour to hour and from day to day, the amount of sulphur dioxide present in the air after washing apparently depends upon the hydrogen-ion concentration of the wash water. This relationship is illustrated in figure 4. As the alkalinity of the wash water decreased because of the absorption of sulphur dioxide, coupled with insufficient additions of the alkaline material, the sulphur dioxide content of the washed

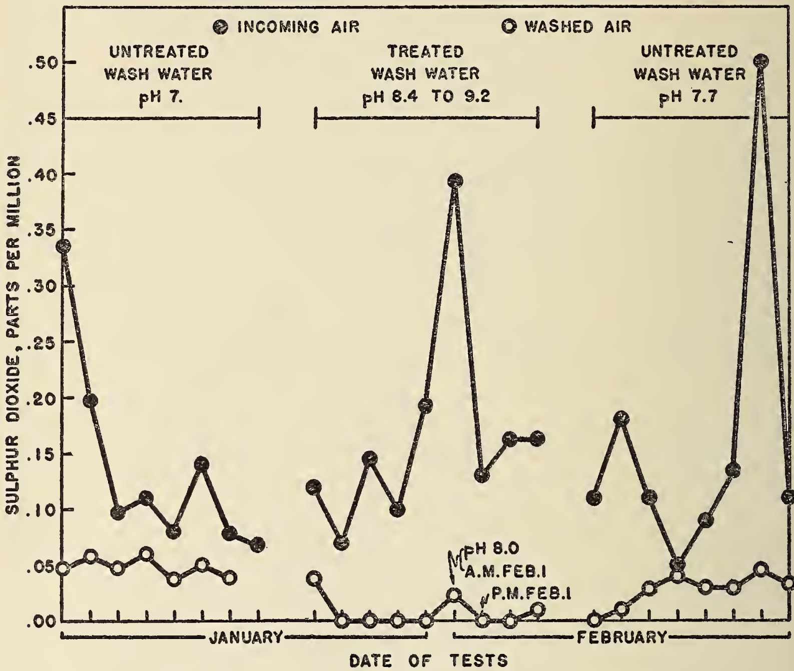

FIGURE 4.—*Relationship of the sulphur-dioxide content of washed air to the hydrogen-ion concentration of the wash water.*

air rose. Air treated with water having a hydrogen-ion concentration of pH 8.6 or above was completely free from sulphur dioxide and, in that respect, suited to use in libraries.

It is therefore recommended that libraries, particularly in localities where a high degree of atmospheric pollution is encountered, be equipped with air washers; or better, complete air-conditioning systems. To insure complete removal of sulphur dioxide from the air, the water in the air washer should be changed at least once a week and treated continuously with an alkaline solution so that the hydrogen-ion concentration of the wash water may always fall within the range pH 8.5 to 9.0. All air returning from the storage spaces should be rewashed to eliminate the chance of recirculating any sulphur dioxide that might have leaked into the system. It is considered best to run the entire air-conditioning apparatus continuously.

V. EFFECT OF LIGHT

The discoloration ("yellowing") and eventual embrittlement of newsprint or similar papers containing crude ground-wood fibers, when exposed to the action of light, is a well-known phenomenon and most librarians take more or less adequate precautions to prevent its occurrence. However, it had been generally assumed that discoloration and embrittlement caused by light always occurred together, and that absence of discoloration after prolonged exposure of paper to light necessarily implied an absence of embrittlement as well. This assumption probably accounts for the lack of protection against light observed in some institutions handling high-grade papers only. No information as to the effect of light upon the strength of papers free from crude fibers could be found in the literature. It, therefore, appeared desirable to obtain information as to the effect of light on papers made from all of the usual types of chemically purified fibers, with respect to discoloration and weakening of the papers, as well as about the role played by the various components of paper. For this purpose test papers were made in the Bureau paper mill from commercial fibers under carefully controlled conditions. Unfortunately, it has been possible to complete only tests of papers made from sulphite wood fiber, and from a much purer wood fiber produced by special chemical treatments. Specimens of these papers were subjected on each side to the action of light from a carbon-arc lamp for a period of 100 hours. The temperature of the test specimens was kept below 40° C during the exposure by blowing air over them. The cooling of test specimens during artificial-light exposures is a necessary precaution that is often overlooked, as the high temperature of the lamp may affect the paper more than the light does.

TABLE 3.—*Effect of light on test papers*

Sample no.	Fiber composition		Sizing	Folding endurance [1]
	Highly purified wood fibers	Sulphite		
	Percent	*Percent*		*Double folds*
901		100	None	320
901–H72 [1]				150
901–L200 [2]				54
902		100	Rosin	180
902–H72 [3]				56
902–L200 [2]				23
909	100		None	3,700
909–H72 [3]				3,200
909–L200 [2]				440
910	100		Rosin	2,500
910–H72 [3]				1,600
910–L200 [2]				300

[1] For test specimen 90 by 15 mm. Average of machine and across machine directions.
[2] Each side exposed to carbon-arc light for 100 hours.
[3] Heated 72 hours at 100° C.

Table 3 contains data on the original folding endurance of one unsized and one sized sample of each type of paper, as well as the folding endurance of the same paper after light exposure and after the heat test. The latter is a form of accelerated aging test that has been extensively employed at the Bureau.[47]

It will be noted that the light exerted a marked deteriorative action as shown by the greatly decreased strength of the specimens exposed to the rays of the arc lamp. This was even true in the case of sample 909, which was quite stable under the heat test. Despite the extensive weakening effect of the light, there was no apparent discoloration of the purer papers and the sulphite papers were only slightly discolored.

These data, although not extensive, show quite definitely that good grades of record papers are susceptible to deterioration by light, and that deterioration from this source may take place without visible evidence. Rasch [48] also obtained data of this kind. He exposed a series of papers consisting of 100 percent of rag fiber, 100 percent of sulphite wood fiber, and mixtures of these fibers, representing the usual grades of bond papers, to the action of direct sunlight. Each side of the specimens was exposed for a period of 100 hours. This treatment, which was probably less severe than exposure to carbon-arc light, produced losses in folding endurance of from 25 to 63 percent. No observations of degree of discoloration were made.

Since perusal of the literature showed that the available knowledge of the effect of light on rosin paper-sizing materials was extremely contradictory, an investigation of the light sensitivity of these compounds was made.[49] It was found that rosin, whether unbleached or purified by bleaching, darkened considerably during exposure to light, that the presence of oxygen was not necessary for this change in color, and that the darkening was accelerated and intensified by the presence of ferrous iron. Ferrous resinate, a compound of ferrous iron and rosin, was also shown to be sensitive to light.

As an extension of this work, papers contaminated with various amounts of iron were made and tested for light sensitivity. The presence of appreciable quantities of iron in the papers was found to increase markedly the degree of discoloration produced by exposure to light. A tendency towards increased loss of strength in the case of the specimens containing iron was observed, but no definite data to this effect were obtained because of the extensive effect of light upon the uncontaminated samples; see table 3.

It is believed that a more precise study of the effect of light, particularly ultraviolet light, upon paper than was possible with the equipment at hand would yield valuable information relative to the preservation of records. Such a study should include an investigation of the effect of monochromatic light of various wave lengths with a view to determining the exact frequencies responsible for paper deterioration. Colored glass is sometimes used for the purpose of filtering out actinic rays of light, but definite data on the efficacy of this practice are lacking. In any case, direct daylight must be regarded as a potential destroyer of all forms of record papers, and its use should be discouraged. If used, its effect should be minimized by diffusion with suitable window glass or curtains over windows. Indirect lighting by incandescent lamps and the use of lead-glass bulbs for such lamps in direct lighting are preferable practices. In storage stacks the lamps should be turned on only when actually needed.

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[47] R. H. Rasch, *Accelerated aging test for paper,* BS J. Research **7**, 465 (1931) RP352.
[48] See footnote 47.
[49] Arthur E. Kimberly and J. F. G. Hicks, *Light Sensitivity of rosin paper-sizing materials,* BS J. Research **6**, 819 (1931) RP307.

VI. VENTILATION OF LIBRARIES

Paper, cloth, thread, adhesives, and leather, the organic constituents of books, are susceptible to decay from chemical changes brought about by deteriorative components of the book materials, or by exterior influences such as sulphur dioxide in the air, and sunlight. There is also the rotting effect of mildew which results from spores carried by the air. All of these deteriorative actions are stimulated by certain temperatures and humidities. The abrasive action of dust has previously been mentioned.

Book paper saturated with water loses nearly all its strength; but it is not conceivable that the paper in a book could ever pick up this amount of water from the air. Perfectly dry paper is relatively brittle. Prolonged exposure of a book to an atmosphere of less than 15 percent relative humidity might render the pages tender. Direct or prolonged heating will also make paper brittle, so books should not be placed near steam pipes or radiators.

The cloth and thread, whether of cotton or linen, are not materially affected by any extremes of humidity or temperature which could normally be expected in a library. The thread in much-used books sometimes gives way to a repeated stress well within its ultimate strength. The cloth may be sized with starch or similar water-soluble adhesive. This may become sticky if the humidity is too high, or brittle if it is too low, and is susceptible to attack by oxygen in the presence of moisture and light.

Glue and casein are colloidal materials containing, normally, much water. If the humidity gets too high (much above 70 percent) they are likely to become sticky, which probably does no harm. But if the humidity drops much below 40 percent, glue which is stored in contact with such an atmosphere for a considerable length of time is apt to become so brittle that the sudden opening of the book will break it. Glue is permanently damaged by prolonged exposure to temperatures below freezing (25° F may be taken as the freezing point of glue containing a little water).

Leather is not affected by temperature or humidity within the ordinary ranges. The oils and greases which are worked into leather to preserve its flexibility have a definite, though very low, vapor pressure. They are gradually lost by evaporation and should be replaced at intervals by rubbing the leather with neat's-foot or similar oil.

Mildew is a term popularly used to designate any one of a variety of vegetable organisms. All of these have certain characteristics in common: they propagate by means of spores, which are almost always present in the air. They can remain dormant for an indefinite period until the conditions become right for their growth. They grow very slowly at low temperatures (40° F), very rapidly at the optimum temperature (which differs with the species), and are killed by high temperatures (some species as low as 100° F). The different species subsist on different kinds of food; many kinds can live on glue and starch, and at least one is capable of digesting the pure cellulose found in cloth and paper. They all require an abundance of water. Unless the growth of mildew continues unchecked for a considerable time, it is not likely to do any harm other than create an unsightly appearance. If the relative humidity is kept under 80 percent, paper, cotton, or leather will not contain sufficient water to support the growth of mildew; glue and starch will. These latter materials can be treated to prevent mildew growth, beta-naphthol being generally used for this purpose.

Dust may be composed partly of the product of the slow growth of mildew. It consists largely, however, of small angular particles of siliceous material. These particles are so small that they can become embedded between the fibers of the leather or the cloth, and perhaps even of the paper. Subsequent flexing of the material may cause the angular dust particles to cut the fibers. The danger of damage from dust is so slight that it can be eliminated by a reasonable amount of care.

Deterioration caused by sulphur dioxide has already been discussed.

It is necessary to consider how the relative humidity in a building varies from time to time. During the summer, if the building is neither heated nor cooled, the temperature and relative humidity of the air inside the building and out of doors will on the average be the same, and the relative humidity prevailing under these conditions is in most cases not injurious to the books. It is true that if a period of relatively cool weather is followed by a period of warm, damp weather, the warm nearly saturated air, coming in contact with the cool books, may deposit moisture on them or increase their moisture content to a point where mildew may develop. In winter the conditions are different. The outside air has a rather high relative humidity, but being cold, its moisture content is small. When this air is heated, its moisture content is not changed appreciably, but while it is warm its relative humidity is much lower than that of the outside air, and as it passes over the books it dries them out in some cases sufficiently to injure them. Hot air is not necessarily dry air, but if cold air is heated without adding moisture to it, its relative humidity is decreased and it becomes "dry." To maintain a higher relative humidity in a heated building in winter, it is necessary to add water vapor as the air is heated.

In general, then, the air in a heated building has a rather high relative humidity in summer and a low relative humidity in winter, even though the relative humidity of the outside air may be nearly the same in both cases. Consequently, during the winter the books dry out, while in summer the moisture content increases in some cases to an extent sufficient to cause injury.

In considering conditions of temperature and relative humidity for the storage of records, economy of operating expense and comfort of the personnel caring for the records must be considered, as well as the preservation of the records, although this must be the determining factor. It is, therefore, recommended that 70° F and 45-percent relative humidity be maintained in storage spaces in the winter, and 85° F and 45-percent relative humidity be maintained during the summer months. It is felt that these conditions are satisfactory for the preservation of records, and the higher temperature recommended for the summer months will result in lower operation costs, as well as lessen the shock to employees upon leaving or entering the conditioned area. Under conditions such as these, the stored material possesses good strength and flexibility, and the growth of molds is minimized.

A positive circulation and diffusion of air through the library, or at least the storage stacks, is desirable, in that it will facilitate proper control of temperature and humidity. It is necessary to take in a supply of outside air only to meet the requirements of the people in the library. Temperature, humidity, and chemical condition of the air can be maintained at their optimum values (so far as the books themselves are concerned) at lowest cost and with greatest ease by recirculation of the air within the building. Dust should be removed from the air.

VII. QUALITY OF PAPER

Although librarians are not responsible for the quality of papers in publications given into their care, they can and have exerted considerable influence in raising the standards for such papers. They are in an advantageous position to study the lasting qualities of the papers, and their observations and reports of the presence of decaying papers in all classes of printed matter have drawn attention to the many cases of impermanent papers bearing records of perpetual value. This is more particularly true of papers made since the early part of the nineteenth century, when the increasing demand for cheaper papers resulted in efforts to find less expensive raw materials and manufacturing processes that gradually led to the development of the present practices. Prior to this time all classes of papers, even newsprint, were generally made from cotton or linen rags, slowly and carefully, entirely or largely by hand, and without much use of chemicals. Most of these papers have withstood the test of time. The search for new fibrous materials brought straw into use by 1830, chemical wood pulp produced by the caustic-soda process in the sixties, and between this time and the eighties, the acid-sulphite chemical wood pulp and ground wood pulp. While ground wood pulp furnished the final solution for cheap printing paper, particularly newsprint, it has been an adverse factor in the preservation of printed material of all kinds. Until the impermanent nature of this and other crude fibers became known by experience with them, they were used indiscriminately in all classes of publications. Coincident with the development of pulping processes for new kinds of fibers, came the use of inexpensive rosin sizing for paper and gradual development of the present machinery for mass production of pulp and paper in an inexpensive way.

The present types of record papers have probably not been in existence for more than 25 to 100 years. The time varies with the kind of paper. This is insufficient time to determine whether any of them will age as gracefully as the old hand-made papers. To obtain information on the influence of different fibers on aging qualities of papers, specimens of papers from over 300 old books and newspapers were examined for state of preservation as related to the kinds of fibers present. The specimens were considered to be in good condition if there was little apparent weakening of the fibers and little or no discoloration. At the other extreme they were rated in bad condition if they broke readily on creasing between the fingers and were highly discolored. Paper that had apparently deteriorated appreciably usually had a light to dark brown color.

The newspaper specimens examined covered very thoroughly the various transitions in paper-making practice outlined above, as it was possible to secure specimens from the files of libraries and publishers representative of newspapers published during the period 1830 to 1900, at approximately 5-year intervals. The specimens were from 24 eastern papers and 12 west-coast papers. The book papers ranged over much the same period as the newspapers, but the publication dates of the books were at irregular intervals, as they were secured more particularly for the study of effect of sulphur dioxide described in section IV.

The results of the fiber analyses of the old papers from the newspapers and books revealed practically identical usage in the past, as far as time periods are concerned, of the various fibers that have been used for such publications. Rag fibers were found exclusively until 1868, when the first straw fibers were found, followed by ground wood in 1869, and chemical wood in 1870. Rags are still commonly used in higher grades of book papers but in newspapers their use is now confined to limited issues made for the permanent files of public libraries. The latest newspaper composed, in part, of rag fibers was dated 1895. From 1867 to 1895 the newspapers, and many of the book papers, were composed of various mixtures of rag, straw, chemical wood, and ground wood fibers. Apparently the present newsprint paper, composed of a mixture of chemical wood and ground wood fibers, became well established by 1895. The latest newspaper containing straw was dated 1885. A few of both the book and the newsprint papers were found to be composed entirely of straw. Ground wood was found in book papers extensively until 1904, but most of the book paper now used is composed entirely of chemical wood fiber. The first of the latter type of paper was found in a book published in 1889.

The comparison of the kinds of fibers found in the papers with the condition of the specimens is striking evidence of the necessity of avoiding low-grade fibers for records of permanent value. This is best illustrated by a review of the results obtained with the newspaper specimens, because they are more thoroughly representative of the various fiber usages than are the book papers. All of the 36 newspapers composed of rag fibers, chemically treated, 57 to 103 years old, were in good condition. Of 17 papers consisting of straw or mixtures of rag, straw, and wood fibers, 53 to 65 years old, 23 percent were in poor condition. Seven of these papers that were in good condition were composed wholly or largely of straw or wood fibers, showing that fibers from these sources may have good life if properly purified. Contrasted with the generally good condition of the papers containing only chemically purified fibers, of 51 papers containing crude ground wood fibers mixed variously with rag, wood, and straw fibers, 33 to 64 years old, 78 percent were in poor condition. Most of these deteriorated papers were so weakened that they would withstand very little handling. The book papers yielded the same findings as the newspapers in respect of influence of purity of fibers on their aging quality. In some of the old books good grades of paper were found mixed with poor grades, which is one cause of uneven deterioration of different pages often observed in old books.

The foregoing quite definitely outlines periods during which publications, even most important ones, may contain impermanent papers because of the use of low-grade fibers in their manufacture. In the case of book papers, as before mentioned, the use of ground wood fibers for the important classes of publications was probably largely discontinued about 1904. Because of the necessity for inexpensive paper, the use of crude fibers in newsprint has continued. Fortunately, the evident impermanence of modern newsprint led to the initiation in 1927, by the New York Times, of the printing of special library editions on high-grade paper, and this practice has since been followed by several other newspaper publishers.

Complete reports of the studies of old book papers and newspapers have been published.[50] [51]

At the request of the American Library Association and the National Association of Book Publishers, a study was made of the quality of the domestic book papers as produced at the time,[52] for the purpose of assisting in the establishment of standards for such papers, from the viewpoint of their use as record-bearing material. In this work 28 papers, representative of the different grades, were subjected to thorough tests for chemical purity, strength, and stability. Their stability was measured by the accelerated aging test previously mentioned, which consists in exposure to dry air at a temperature of 100° C for 72 hours, followed by tests for changes in chemical and physical properties. This measure of stability appears to be valid, as the results are in accord with experience with the aging quality of papers, and were found to agree well with those obtained by exposures to sunlight, exposures to air at more normal temperatures,[53] and a 4-year period of natural aging.[54] Richter has reported similar findings.[55] [56] [57] [58] As in the case of the old book papers studied, other things being equal, the more stable papers were those containing the purer fibers, that is, fibers having a high content of alpha cellulose and a low copper number. Good quality in this respect had no constant relation to the kind of fiber present or its initial quality, which points to the necessity of careful processing of fibers, as well as careful selection of them, for the manufacture of stable papers. In many cases high acidity from the alum used in rosin-sizing the paper was apparently the cause of poor stability. Rosin itself has been shown to be a potential promoter of deterioration, and although the amounts found in these papers were not excessive, it is questionable if the use of rosin in book paper is necessary. Clay filler, the remaining principal component of book paper, was found to have no harmful effect, as is to be expected because of its chemical inertness.

From the above considerations a classification of book papers based on fiber purity in terms of alpha cellulose and copper number, a minimum of injurious chemicals, and strength, was suggested. This comprises four grades, ranging from paper for permanent records to paper for records of temporary value.

The tests indicated that the quality of paper available at the time for permanent records was not in general as good as considered desirable, and this was attributed to the probability of good printing quality having been given more attention than permanence. The

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[50] A. E. Kimberly and A. L. Emley, A Study of the Deterioration of Book Papers in Libraries, Misc. Pub. BS 140 (1933).

[51] B. W. Scribner, Preservation of Newspaper Records, Misc. Pub. BS 145 (1934).

[52] J. O. Burton, *Permanence studies of current book papers*, BS J. Research **7**, 429 (1931) RP349.

[53] R. H. Rasch, *Accelerated aging test for paper*, BS J. Research **7**, 465 (1931) RP352.

[54] R. H. Rasch and B. W. Scribner, *Comparison of natural aging of paper with accelerated aging*, BS J. Research **11**, 727 (1933) RP620.

[55] *Researches on wood fibers as a paper-making material.* J. Franklin Inst. **212**, no. 4 (October 1931).

[56] *Accelerated aging tests for determining permanence of papers.* Ind. Eng. Chem. **26**, no. 11, 1154–7 (November 1934).

[57] *Relative permanence of papers exposed to sunlight.* Ind. Eng. Chem. **27**, no. 2, 177–85 (February 1935).

[58] *Relative permanence of papers when exposed to sunlight. II.* Ind. Eng. Chem. **27**, no. 4, 432–9 (April 1935).

situation in this respect has since been materially improved by the increased attention given permanence requirements by paper manufacturers, printers, and librarians.

VIII. INSECTS

The protection of stored records from the depredations of insects is one of the most serious and difficult problems of the librarian. Constant warfare must be waged against this form of destruction. Climatic conditions render this problem more or less acute in different localities, but no library is free from it. The cellulose in paper and fabric attracts certain species of insects, and some kinds are particularly fond of other book components, such as glue, starch, or casein.

The more or less common pests—the termites or white ants, the various species of cockroaches, and the silverfish—are destroyers of printed material, and methods of poisoning or trapping them are well known. Advice as to extermination of specific insects of this kind can be obtained from the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, Washington, D. C.

Some protection against insects is secured by the use of poisonous or repellent materials incorporated in bindings and in varnishes and lacquers used to coat books.[59] In some cases fumigation is resorted to. The following fumigants, used in the concentrations given, are said to be 100 percent effective in killing all storage insect pests within 24 hours:[60] Hydrocyanic acid gas from 1 lb of sodium cyanide per 1,000 ft^3; ethylene chloride-carbon tetrachloride, 14 lb/1,000 ft^3; carbon disulphide, 6 lb/1,000 ft^3; ethylene oxide-carbon dioxide, 30 lb/1,000 ft^3; methyl formate-carbon dioxide, 28 lb/1,000 ft^3. The mixed gases, combined in the correct proportions, can be obtained ready for use. As no authentic information was available relative to the possible effects of these fumigants on paper, representative book and writing papers were exposed to them for 24 hr and tested for evidences of deterioration. In no case was any significant effect found, therefore it was concluded that normal fumigation of documents with these materials can be done safely.[61] Vacuum chambers are desirable when large volumes of material are to be fumigated, but are not necessary for treatment of small amounts of materials which can be spread out so that the fumigant has ready access to them.

The Huntington Library has made considerable study[62] of the elimination of the so-called "bookworms" (*Sitodrepo panicea*), which are particularly harmful and very difficult to combat. The insect that causes the bookworm trouble is commonly known as the drugstore beetle.[63] The beetle itself is a voracious eater of nearly all kinds of materials, and it has the further bad habit of depositing its

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[59] M. S. Kantrowitz, F. R. Blaylock, and G. G. Groome, Starch-filled Book Cloth, U. S. Govt. Printing Office Tech. Bul. 21 (1934).

[60] The following U. S. Department of Agriculture articles have been issued relating to the killing of insect pests:
E. A. Back and R. T. Cotton, Farmers Bul. 1670 and 1483.
E. A. Back, R. T. Cotton, and H. D. Young. The Use of the Ethylene Oxide-Carbon Dioxide Mixture for Treating Stored Grain. Letter Circular.
E. A. Back, Farmers Bul. 1353.
W. E. Hinds, Farmers Bul. 799.
I. E. Neifert, F. C. Cook, R. C. Roark, W. H. Tonkin, E. A. Back, and R. T. Cotton, Bul. 1313.

[61] Charles G. Weber, M. B. Shaw, and E. A. Back. *Effects of fumigants on paper*, J. Research NBS **15**, 271 (1935) RP828.

[62] Thomas M. Iiams, The Library Quarterly **2**, no. 4, 375 (1932).

[63] L. O. Howard and C. L. Marlett, The Principal Household Insects of the United States, Washington, D. C.; C. Houlbert, Les Insectes ennemis des Libres, Paris (1907).

eggs near the surface of book bindings or on the edge of the leaves. As soon as the larvas are hatched, they eat their way to the interior of the book, then again to the surface when ready for the chrysalis stage, and a full-grown beetle finally emerges. According to the report of the Huntington Library, the only way to exterminate this pest is to kill the larvas by forcing poisonous gas into their tunnels in the books. They found that vacuum treatment was necessary for killing both larvas and eggs. The fumigant "carboxide" is used in a large vacuum chamber, especially designed for the purpose, which accommodates several trucks of books at one time.

Further references to information on this subject will be found in the general review of literature in section II.

Librarians are cautioned that hydrocyanic acid, formaldehyde, and carbon disulphide are extremely poisonous to human beings, and are quite inflammable. Fumigation with such substances should be conducted only by an expert.

IX. PROTECTIVE COATINGS

Archivists, librarians, and others desirous of preserving fragile documents and newsprint or other similarly fugitive paper are confronted with the necessity of treating the paper in such a manner as to render it more resistant to handling, and to retard the processes of deterioration as much as possible. The mode of treatment must be reasonably low in cost, simple, and easy of application. In addition to being more stable, it is desirable that the paper after treatment shall not be inordinately increased in bulk and weight. Increased bulk is particularly to be avoided, as storage space is always at a premium in the average depository.

In general, two methods of applying protective coatings have been used; namely, building up a film upon the surface of the paper sheet by dipping it into or spraying upon it a solution of a cellulose ester such as cellulose nitrate or cellulose acetate, or by causing a previously formed film to adhere to the paper with or without an adhesive. Results obtained by treating paper with solutions of cellulose esters have not generally proved satisfactory from the standpoint of either service or economy.

The application of japanese tissue, a thin, tough paper of high chemical purity, has been extensively practiced, using a mixture of rice starch and tapioca dextrin as an adhesive. This material, which may be applied by hand or with the aid of apparatus such as that designed for the purpose by the New York Public Library, increased the strength of newsprint greatly. Paper treated in this manner also resisted the effects of the heat test satisfactorily. The tissue itself showed practically no changes after subjection to the accelerated aging procedure. However, this method of treatment was found to be disadvantageous in that the weight of the treated paper was almost double the original weight and the bulk was trebled, which is undesirable. Moreover, the ease with which the contents of the newspaper were read was considerably diminished because of the semi-transparent nature of the tissue paper.

It was thought that this last difficulty could be removed by substituting transparent viscose-cellulose sheets, of which Cellophane is an example, for the japanese tissue. This substitution proved to be unsatisfactory since the cellulose sheeting itself exhibited unsatisfactory permanence as shown by the fact that its alpha-cellulose content was found to be only 77.4 percent and was decreased to 72.6 percent by heating at 100° C for 72 hours.

The usual method of treating a document is to cover each side of it with a coarsely woven silk fabric called "crepeline." The fabric is caused to adhere to the surface of the paper by means of thin starch paste. This procedure, which requires considerable experience, increases the durability (resistance to handling) of the document, but does not exert a favorable effect upon its permanence. In fact, because of the type of adhesive used, materials so treated may be rendered more susceptible to attack by fungi and insects which prey upon paper.

The recent development of cellulose acetate foil, 0.001 inch thick, led to the trial of this material as a preservative for newsprint. Since cellulose acetate is thermoplastic (i. e., flows under the influence of heat and pressure), it was easily applied by placing a sheet of newsprint between two slightly larger sheets of cellulose acetate and transferring this combination to a hydraulic press where, under the action of heat and pressure, one homogeneous unit was obtained. Newsprint treated in this manner was found to be very stable to the heat test and to the action of light from a carbon arc. Moreover, no impairment of legibility was caused, nor was there an objectionable increase in bulk, as the thickness of newsprint was increased only 0.0005 inch by this treatment. However, the weight of a specimen of newsprint covered with cellulose acetate foil 0.001 inch thick, was found to be approximately two and one-half times that of a similar unprotected specimen. Other workers engaged in similar researches abroad concur in these findings.

The so-called laminating process, using cellulose acetate foil, as described in the foregoing paragraph, yields a product which is infinitely more satisfactory from the standpoint of increased resistance to deterioration. Documents laminated with cellulose acetate foil by means of heat and pressure alone, resist the accelerated aging test very well and are very resistant to attack by insects and molds. They retain the flexibility of the untreated paper and are easily legible.

Cellulose nitrate sheetings, which include celluloid, are relatively unstable and may have a deteriorative effect on papers brought in contact with them.

The New York Public Library has reported [64] the results of trials of a wide variety of protective materials, including chiffon, silk, cellulose lacquers, varnish, and japanese tissue paper. They considered the last named the most suitable of those tried.

X. WRITING INKS

That writing inks may be deteriorative to paper is well known, as instances have been observed where the ink has eaten its way through the paper of old documents. Moreover, as the usual type of writing ink is acid, it would be expected to affect paper adversely. While considerable study of this subject has been reported by Herzberg [65] and others, their findings have been rather contradictory in respect of

[64] Harry M. Lydenberg, *Preservation of modern newspaper files*, Library J. 40, 240 (1915).
[65] W. Herzberg, Papier-fabr. 54, no. 2, 104 (1923).

the component or components of the inks that may cause deterioration of paper. Their tests were made on papers that may have been somewhat different from the present domestic papers, and little attention was given to the proportion of ink and paper. In view of these considerations, further study of the subject seemed desirable, particularly as the Organic Chemistry Section of the Bureau desired to include a study of this kind in a general investigation of the properties of writing inks.

For the study, seven writing papers were selected which were representative of the commercial range of fibers, and of the sizing materials usually present in such papers. The Organic Chemistry Section prepared the various inks used for experimentation, and inked the test specimens of papers. The ink lines were drawn across one-half of the sheets of paper, with a drawing pen, of such width and spacing as to simulate the proportion of ink and paper of the average written document. The inked specimens were then subjected to the heat test, and the relative retention of folding endurance of the inked and uninked portions of the papers was determined. The inks used were the usual gallotannic acid-hydrochloric acid type, one of which was prepared according to the U. S. Government specification [66] for writing ink, and the other the same, except that sulphuric acid was used instead of hydrochloric. Lines were also drawn with the components of the Government standard writing ink in various mixtures, or used separately, in solutions of the same concentration as in the ink.

It was found that all of the papers were appreciably weakened by the accelerated action of these inks. The inked portions of the papers lost from 13 to 50 percent more of their initial folding endurance than the uninked portions. With respect to the different components, solutions containing, respectively, hydrochloric acid, ferrous sulphate, gallic acid, tannic acid, and a mixture of hydrochloric acid and ferrous sulphate, produced losses in folding endurance of about the same magnitude as the ink itself. The other components had relatively little effect.

In view of these findings E. W. Zimmerman, of the Organic Chemistry Section, prepared inks of various formulas, until finally an ink was found that caused practically no loss of folding endurance of papers inked with it. This ink was prepared with ammonium ammoniumoxyferrigallate according to the method of Silbermann and Ozorovitz.[67] The solution used had the same concentration of iron as that of the standard Government writing ink. The writing qualities of this ink were satisfactory, as was also its lack of sedimentation on standing. While some further study of its use is desirable, it appears to offer considerable promise for use in documents that are to be retained a great number of years.[68]

XI. PRESERVATION BY REPRODUCTION

It is often desirable to preserve records by reproduction to prevent loss of those which are in impermanent form, or to minimize the danger of loss of permanent records through wear from handling or

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[66] Federal Specification TT-I-563 (Dec. 9, 1930).

[67] Silbermann and Ozorovitz, Bul. soc. stiinte Bucuresti **17**, 43 (1908); Chem. Abstracts **2**, 2685 (1908); Chem. zentr. ii, 1024 (1908).

[68] E. W. Zimmerman, C. G. Weber, and A. E. Kimberly, *Relation of ink to the preservation of written records*, J. Research NBS **14**, 463 (1935) RP779.

through other hazards. Photographic reproduction on both paper and motion-picture film is commonly employed.

Extensive tests of photographic papers, particularly photostat papers, showed that while their quality varied considerably, papers suitable for permanent record use are available. Prints made on stable paper are stable and do not fade if they are properly fixed and washed.

The use of motion-picture film is growing rapidly because of the low cost of this form of reproduction and the conservation of space it permits. For example, a storage space of 108 cubic feet is required in the New York Public Library for 1 year's issue of the New York Times, bound, as compared with ⅓ cubic foot for film copies. The film copies, of course, are made in miniature and therefore the image must be magnified for reading. There has been considerable development of photographic and reading devices for records contained in reduced size on both film and paper.

Because of the rapid expansion of the use of film records, information on their stability, and how they should be used and stored, became an imperative necessity. There was practically no authoritative information of this kind available when the Bureau undertook its film investigation.

Both the acetate and the nitrate types of films have been studied by using extremes of temperature and moisture conditions as accelerated aging tests, and by putting them through various cycles of temperature and humidity conditions to find the optimum storage conditions. Any tendency of the films to become brittle under such treatments has been studied by testing for decrease in folding endurance. Chemical deterioration of the film base has been tested by finding whether any drop in viscosity of solutions of them, loss in weight, and increase in acidity occurs. In addition, the nitrate film has been tested for time required for acid fumes from the film to discolor a test paper on heating—a test used for guncotton.

When new nitrate films were heated in dry air at 100° C and reconditioned, which is the accelerated aging test used for paper, they became permanently brittle in 10 days, and evidence of their extreme chemical deterioration was found. Under the same conditions, new acetate films retained good flexibility even after heating for 30 days and showed little evidence of chemical change. On heating the films in an atmosphere of 95-percent relative humidity both types showed evidences of deterioration, although the nitrate films again were much less stable than the acetate. On putting the films through a cycle of various humidity conditions, it was found that the nitrate films retained their flexibility better than the acetate on loss of moisture, and showed less dimensional changes. The acetate films became quite brittle if they became too dry, but their flexibility and approximately their original dimensions were restored on exposing them to a medium degree of humidity.

While the evidence is not yet complete, information already obtained shows that acetate films offer considerable promise for permanent record use if properly made, and if care is taken to prevent them from drying out too much. They should be stored in air having a relative humidity of about 50 percent. After they are used in the projection machine, they should be exposed to air of this humidity in such a way that the air has free access to all parts of the film, to restore moisture that may have been lost, and they should not be reused until moisture equilibrium has been obtained. This moisture condition plus a low temperature, not above about 50° F, is suitable for prolonging the life of nitrate films. Such conditions have been recommended by the Society of Motion Picture Engineers Committee on Preservation of Motion Picture Films.

Films should be cleaned occasionally to remove any dust, fingerprints, or oil from the projector that may be present. In an investigation of various cleaning liquids for this purpose, Crabtree and Carlton [69] found that chemically pure carbon tetrachloride was quite satisfactory because it is a good solvent for oils and fats, evaporates readily, is noncombustible, and is inexpensive. They recommended that the film be wiped gently, to avoid scratching it, with silk plush moistened with the carbon tetrachloride if the cleaning is done by hand, but they state that for film in reels a good type of cleaning machine is preferable. Inhalation of carbon tetrachloride fumes should be avoided because they are very toxic.

Other problems such as effect of the light of projectors, effect of contaminated air, and the resistance of photographic emulsion to aging and to wear, remain to be studied.

The results of the film studies have been published.[70] [71]

XII. RECAPITULATION OF RECOMMENDED PRACTICES

The National Archives Building, Washington, D. C., is an exemplification of the more important practices for the preservation of records recommended in the foregoing. In planning this depository of Government records, these recommendations have been followed, and use has been made in general of the most advanced scientific, engineering, and architectural knowledge, to safeguard the records. A large air-treating system capable of handling 330,000 cubic feet of air a minute will insure the purity and proper tempering of the atmosphere throughout the building. A feature of this system will be the washing of the air with an alkaline solution to remove positively any acidic contamination which might otherwise find its way into the storage space. The pH of the wash water will be maintained at 8.5 to 9.0. It is planned to maintain a relative humidity of 55 percent in the storage spaces, and of 45 percent in the workrooms. The latter condition is the better adapted to human beings. The temperature throughout will be kept at 70° F during the winter and 80° F during the summer. The higher temperature during hot weather is more economical and is more healthful for the personnel, as it avoids sudden exposure to too great change in temperature in entering or leaving the building. Continuous maintenance of the humidity within 2.5 percent, and of the temperature within 1° above or below the chosen conditions is believed feasible. The temperature and relative humidity recommended were chosen because they represent a range in which the substances stored exhibit good strength and flexibility, and because such conditions are excellent so far as the comfort of workers is concerned (see Air Conditions and the Comfort of Workers,

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[69] Trans. Soc. Motion Picture Eng., no. 30 (August 1927).

[70] *Care of filmslides and motion-picture films in libraries,* C. G. Weber and J. R. Hill, J. Research NBS **17**, 753 (1936) RP 753. J. Soc. Motion Picture Eng. **27**, no. 6 (December 1936).

[71] *Stability of motion-picture films as determined by accelerated aging,* J. R. Hill and C. G. Weber, J. Research NBS **17**, 871 (1936) RP 950. J. Soc. Motion Picture Eng. **27**, no. 6 (December 1936).

Industrial Health Series, no. 5, Metropolitan Life Insurance Co., New York). The growth of molds and fungi is minimized under these conditions.

Daylight is excluded from the storage spaces of this building; the necessary illumination is supplied by small incandescent lamps turned on only as needed. Another interesting precaution is the use of glazed tile, and the encasing of concrete columns in nonferrous metal, to minimize abrasive dust. Coated or nonferrous metals are used, where metal is required in the storage spaces, to eliminate the necessity of repainting, which would be hazardous to the stored records.

Stored material should never be removed from the purified air in libraries, as it will retain acidity that may be acquired from sulphur dioxide in polluted air.

New acquisitions of records should be fumigated to kill "bookworms" or other insect life that may be present. Fumigants should be chosen with consideration of their possible effect on paper and other library materials.

Frequent dusting with vacuum appliances will minimize the abrasive action of dust, as well as destructive bacteria and pests.

Japanese tissue paper has given good service when used as a protective covering for impermanent papers, and transparent celluose acetate sheeting appears to be another suitable material for this purpose. For reproduction of records, photographic prints on permanent paper are satisfactory, and apparently cellulose acetate film is suitable for the purpose.

It is realized that the complete use of all of the precautions mentioned is expensive. But this expense is not out of line with that of the purchase of record material, and the operating and housing expenses of libraries, and, obviously, any library housing records of perpetual value should consider the cost of their preservation an indispensable part of its budget. In this connection this report can well close with the following which is quoted from the article by Thomas M. Iiams.[72]

> In October of the year 1902 the short-lived periodical known as the Bibliographer published an essay entitled Of Bibliophilism and the Preservation of Books, by Henry French, later identified as the great collector, Robert Hoe. In this article the author makes the unqualified statement that:
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> "Palatial fireproof buildings with imposing facades, monumental staircases and lofty halls and reading rooms, elaborate and learned classifications and systems of catalogs, with ingenious machinery for the almost automatic delivery of books to readers, however perfect and efficient, furnish no guarantee for the proper care of literary treasures."

WASHINGTON, December 11, 1936.

[72] Thomas M. Iiams, The Library Quarterly 2, no. 4, 375 (1932).

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